Astronomy & Astrophysics manuscript no. n24a
October 19, 2010

On the mutually inclined orbits of planets in the CoRoT-7 extrasolar planetary system

CoRoT-7bcd

R. Dvorak[1], J. Schneider[2], V. Eybl[1]

[1] Universitätssternwarte Wien, Türkenschanzstr. 17, A-1180 Wien, Austria
[2] LUTH, Observatoire de Paris-Meudon, 5 place J.Jansen, F-92195 Meudon, Paris, France

Received -; accepted -

ABSTRACT

Aims. We propose a method to be able to decide whether the planets of CoRoT-7 are moving on mutually inclined orbits in the order of $i > 10°$.
Methods. The extrasolar system CoRoT-7 is very special with respect to the closeness of the planets to the host star, which results in a fast dynamical development. It would therefore be possible to determine the inclination of the innermost planet CoRoT-7b with respect to the observer after an observation of at least three years from space with the satellite CoRoT with sufficient precision. Different inclinations would cause different duration of the transit times of a planet in front of the star and would therefore give us a better knowledge of the architecture of this system. With the aid of numerical integrations and analytical estimations we checked how inclined orbits of additional planets would change the transit duration of CoRoT-7b
Results. After 3 years of observations when an additional planet would be on a inclined orbit with respect to CoRoT-7b ($I_{mutual} > 10°$) an increase of the order of minutes could be observed for the transit duration.

Key words. extrasolar planets, CoRoT-7, inclined orbits

1. Introduction

Most of the more than 440 extrasolar planetary systems (=EPS)[1] are single planetary systems, but as of October 2010 there are some 50 multiplanetary systems, where between 2 and 7 planets are known to orbit their host stars. A very special case is the newly discovered system HD 10180 with seven planets orbiting an early G-type star (Lovis et al. 2010). Certainly the small number of multiple EPS is a biased sample because it is highly improbable that there is just one planet around a star. From the theory of formation one expects that several planets may originate from the disk of gas and dust around a young star, like it is the case for the solar system.

An interesting fact is that many of the EPS-planets seem to move on large eccentric orbits and consequently – when we expect more planets orbiting the star – strong perturbations will act on the planets and therefore the orbital elements may change significantly. Unfortunately our present methods to detect planets are just snapshots of the dynamical life time such that we don't have access to the dynamical evolution of a system. This is especially true for the detections via RV measuremenent where it is impossible to determine the inclinations of the orbital planes with respect to the observer. Even via transit observations of one planet combined with the measurement of radial velocities it is impossible to determine mutual inclinations of the orbits of planets when only one – clearly the innermost – is transiting. The main problem to be solved would be to observe such an EPS for sufficiently long times to be able to see more than one snapshot in the dynamical evolution of the system. We are now in the same situation in astronomy as we had been during the last centuries when scientists wanted to determine the proper motion of stars or the orbital elements of double stars. Within the EPS most of the planets, especially the ones which we observe via transits, are relatively close to the host star and they have relatively large masses. So we might hope to see a signature of additional planets influencing the orbit of the inner planet which may result in a change of the transits times and/or the duration of the transit. Up to now it was impossible to make such precise measurements using ground-based observation but with the possibility of using satellites the situation changed. The CoRoT spacecraft[2] (launched 2006) and the NASA Kepler mission (launched 2009) permit very accurate measurement of light curves of transiting planets in terms of photometric precision and timing of transits. The recent extension of the CoRoT mission for another three years is important with respect to the observation of Transit Time Variations (TTV) and also possible Transit Duration Variations (TDV) on a time line of several years.

Send offprint requests to: R. Dvorak, e-mail: dvorak@astro.univie.ac.at
[1] see http://exoplanet.eu
[2] The CoRoT space mission has been developed and is operated by CNES with the contribution of Austria, Belgium, Brazil. ESA, Germany and Spain

2. EPS with planets on inclined orbits

The discovery of transiting planets with short periods makes searches for additional planets in an EPS via TTV and TDV feasible. There are a number of recent publications concerning the possible perturbations in such systems where outer planets with eccentric or even inclined orbits with respect to the innermost planet are present.

Mardling (2010) was investigating three of such systems, namely HAT-P-13, HAT-P-7 and WASP-17. All three have orbital periods 2.2 days $< P <$ 3.7 days and for HAT-P-13 an additional planets far away (P = 448 days) on a large eccentric orbit (e = 0.666) is confirmed. The eccentricity of the inner planet, assuming coplanar orbits, may suffer from larger variations due to mutual inclinations of two planets, where the outer one is dominating the angular momentum. This effect of amplitude variations is increasing with increased mutual inclination.

An important effect when two planets are moving on inclined orbits is the Kozai resonance which has a stabilizing effect for orbits with $40° < i_{mut} < 60°$ having large eccentricities. In an article by Nagasawa et al. (2008) the effect of coupling between mutual scattering, the Kozai mechanism and by tidal circularization was studied with the aid of orbital integrations. They developed a theory that a planet with small semimajor axis may not be formed by a type II migration because of planet-disc interaction, but through an excitation of the eccentricity because of the Kozai mechanism to values close to $e = 1$ such that the pericenter is close to the host star. Then the tidal friction may circularize the planet's orbit and as a consequence the authors predict that close-in-planets may have large inclinations up to retrograde orbits.

Libert & Tsiganis (2009a) treated the action of the Kozai resonance for five multiplanetary systems which are not in Mean Motion Resonances (=MMR), namely υ Andromedae, HD 169830, HD 12661, HD 74156 and HD 155358. They found out by numerical studies in which they varied the unknown inclinations and also the nodal longitudes, that with the exception of HD 155358 all of them could be in the Kozai resonance when the mutual inclination is larger than 45°. In another investigation by Libert & Tsiganis (2009b) the role of mutually inclined orbits with respect to the stability of the orbits have been made in cases when the planets are in MMR. The authors have undertaken a parametric study varying masses and orbital parameters of the planets where they also took care of the migration rate and the rate of eccentriciy damping. It turned out that due to a capture process in the early phases of the system formation besides the 2/1 MMR (which was treated by Thommes & Lissauer 2003) also in the 3/1, 4/1 and 5/1 MMR the mutual inclinations may reach values as high as 70° when the eccentricity of one planet is larger than $e > 0.4$. Due to their results they say that *our simulations show that inclination excitation is a common outcome, as long as eccentricity damping is not too strong.*

The case of TrEs-2b was explored by Scuderi et al. (2010); this is an EPS with a planet with a period P = 2.4 days. Using older transit observations from 2006 by O'Donovan et al. (2006) and comparing them to the ones of the Kepler mission recently published by Gilliland et al. (2010) they could not find significant changes in the orbital parameters since the discovery of that planet.

In another system, GJ436, the transiting planet has a period of P = 2.6 days but a surprisingly large eccentricity of e = 0.15. Batygin et al. (2009) – using secular evolution of a two and also a three planet system describing GJ436 – succeeded in understanding this fact: the circularization has very long times scales when other planets on eccentric orbits are present which may even move in almost the same orbital plane as GJ436b.

A different topic in astronomy, namely the observation of period variations in eclipsing binaries due to the presence of a third component, offers possibilities of studying the so-called transit time variations (TTV) also in the analysis of transit photometry of extrasolar-planets (Borkovits et al. 2010). But also the duration of an eclipse was studied in the context of EB, and which is the consequence of an influence on the inclination of the two components with respect to the line of sights.

The subject of this article, the extrasolar planetary system CoRoT-7 is hosting one planet with the very small period of P = 20 hours and at least one other planet. We did numerical investigations for different sets of parameters which may cause a visible change in the transit observations especially with respect to the possible change of the inclination of the innermost planet CoRoT-7b.

3. The extrasolar planetary system CoRoT-7

The EPS CoRoT-7 contains one transiting planet CoRoT-7b (Léger et al. 2009) and one non transiting but confirmed planet CoRoT-7c detected by radial velocity (Queloz et al. 2009). A reanalysis of RV data led to the assumption that there could be a third planet in this system (Hatzes et al. 2010). CoRoT-7 is – up to now – a unique example for an EPS where the dynamical time scales are very short which is due to the closeness of the planets to the host star. The short periods of 0.85, 3.7 and 9 days for the three planets mean that the system is under very fast development: an integration time of a million years of CoRoT-7 in a numerical experiment is comparable to an integration of 100 million years for the solar system. Effects caused by mutual perturbations of the planets will be visible on short time scales. We list in Table 1 the orbital elements of the CoRoT-7 planets, showing the results obtained from two different analyses of the data.

4. Investigation of mutually inclined planets in the CoRoT-7 system

Former estimations showed that the regions where the CoRoT-7 planets are moving are very stable (e.g. Hatzes et al. 2010). We show that even inclinations of $i_{7cb} \sim 60°$ have no big influence on the eccentricity of the planets which would make the system unstable (see Fig. 3). The eccentricity changes are well inside the probable errors in the derived element eccentricity. The situation is completely different however for the inclination, because the duration of a transit is very sensitive to it. According to the published values of the inclination, respectively the errors ($i = 80.1 \pm 0.3°$), a shift of several tenth of degrees should be observable. In this section we will describe the numerical experiments and the results we obtained.

It is particularly interesting whether one could determine how much the transiting planet would be influenced with respect to its inclination; this would have consequences for the transit time and the transit time duration. Therefore different test computations

Table 1. Orbital elements of the CoRoT-7 planets

Parameters	CoRoT-7b	CoRoT-7c	CoRoT-7d
	Data from [1]		
mass [M_{Earth}]	4.8±0.79	8.39±0.89	
a [AU]	0.0172±0.00029	0.046	
P [days]	0.853585±2.4×10^{-5}	3.698±0.003	
e	0	0	
i [degree]	80.1±0.3	-	
	Data from [2]		
mass [M_{Earth}]	6.9±1.4	12.4±0.42	16.7±0.42
a [AU]	0.017	0.045	0.08
P [days]	0.853589 ±0.00059	3.691 ±0.0036	9.021 ±0.019
e	0.0	0.080±0.050	0.0±0.05
i [degree]	80±0.3 [3]	≤85 [3]	-

[1] http://exoplanet.eu
[2] Hatzes et al. (2010)
[3] Queloz et al. (2009)

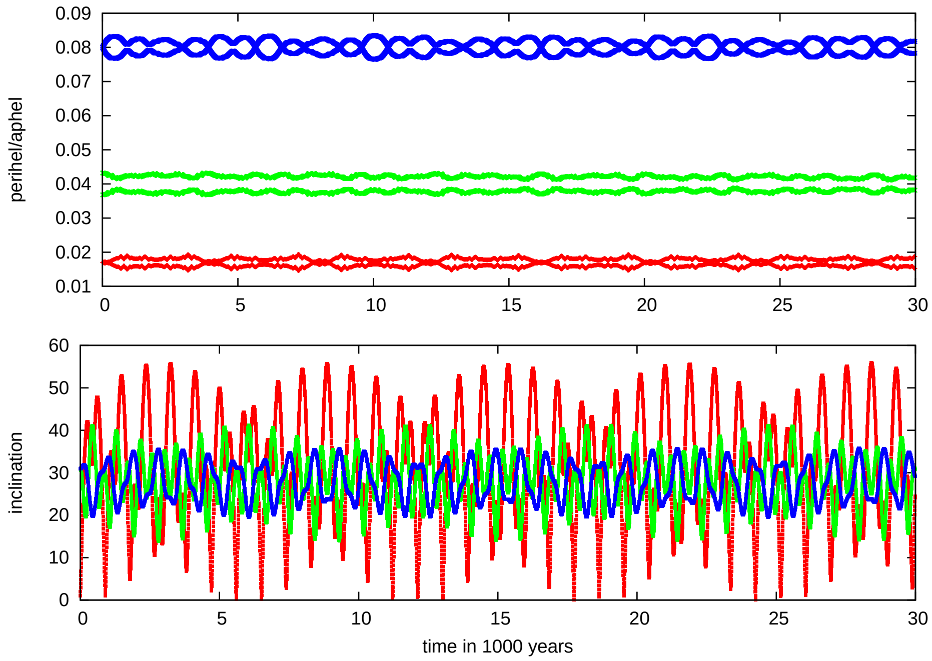

Fig. 1. Change in the perihelion and aphelion distances (upper graph) and inclinations (lower graph) for the CoRoT-7 planets with initial inclinations $i_{7c} = i_{7d} = 30°$ and $i_{7b} = 1°$ during 30,000 years (for colour figures see the online version of this journal).

have been undertaken numerically (see Section 4.1) as well as using an analytical approach (see Section 4.2) for inclined planets in the CoRoT-7 system.

4.1. Numerical results for the two planet case

In this section we considered only the two confirmed planets in the CoRoT-7 system; an extension to the possible case of three planets can be found in Section 4.3. In Figs. 2, 3, 4 and 5 we show the effect on the inclination of CoRoT-7b caused by a difference in the ascending node ($\Omega_{7b} = 20°$ and $\Omega_{7c} = 140°$ = Run A, respectively vice versa = Run B). For each run, the following initial inclinations were used: $i_{7b} = 1°$ and $i_{7c} = 30°$, the time scale for the integration was 3.10^4 years.

In Fig. 2 there is no visible difference between Run A and Run B over a time period of 30,000 years; note that CoRoT-7b reaches inclinations up to $i_{7b} = 47°$. A closer look at a shorter period of time (1,000 years) shows a slight time shift for the evolution of the inclination of CoRoT-7b (Fig. 3). Zooming into the first 100 years of the integration it turns out that the time shift is caused by a different behaviour during the first ten years: while i_{7b} increases immediately in Run A, in Run B it decreases at first, but starts to increase after about ten years. From this point on the dynamical behaviour is qualitatively and quantitatively the same.: The thick

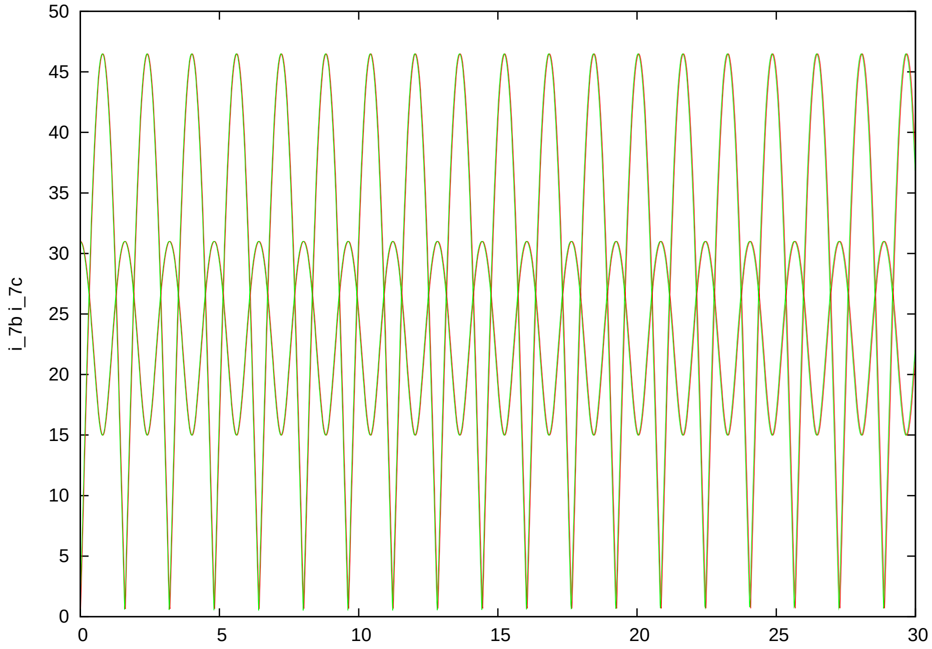

Fig. 2. Evolution of the inclination for CoRoT-7b and CoRoT-7c during 30,000 years of integration with initial inclinations $i_{7b} = 1°$ and $i_{7c} = 30°$. There is no visible difference between Runs A and B (for details see text).

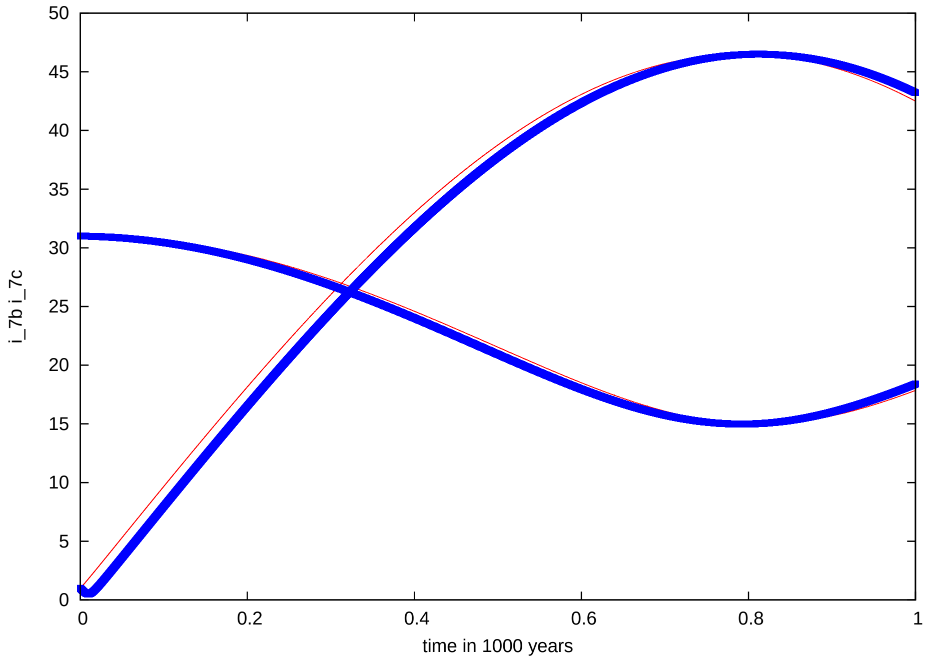

Fig. 3. Evolution of the inclination for CoRoT-7b and CoRoT-7c during the first 1,000 years of integration with initial inclinations $i_{7b} = 1°$ and $i_{7c} = 30°$. Run A and Run B are shown as thin and thick lines, respectively.

and thin line in Fig. 4 show the same slope after the initial ten years. This time shift remains during the whole time which can be seen in Fig. 5, where we plotted the respective evolution of the inclinations after several thousand years.

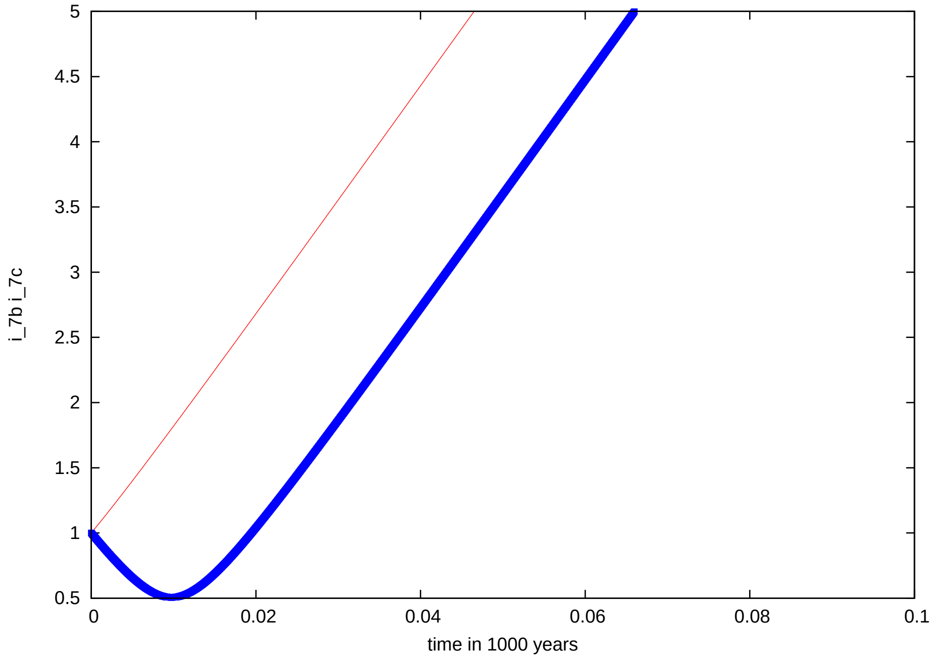

Fig. 4. Detail of Fig. 3: Evolution of the inclination for CoRoT-7b and CoRoT-7c during the first 100 years of integration. Run A and Run B are shown as thin and thick lines, respectively.

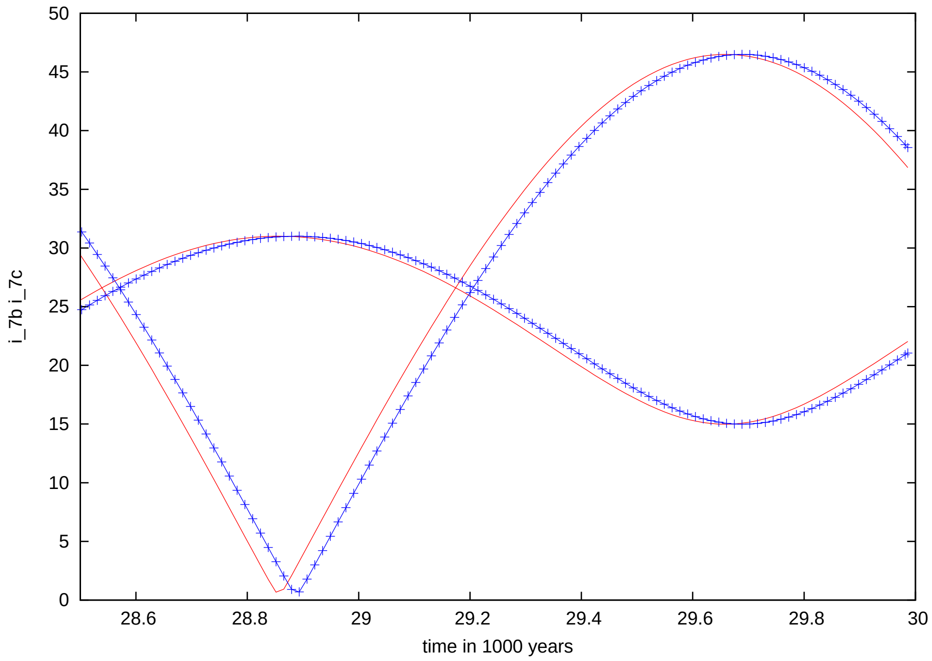

Fig. 5. Evolution of the inclination for CoRoT-7b and CoRoT-7c for the last 400 years of the 30,000 year integration time. Run A and Run B are shown as solid and crossed lines, respectively.

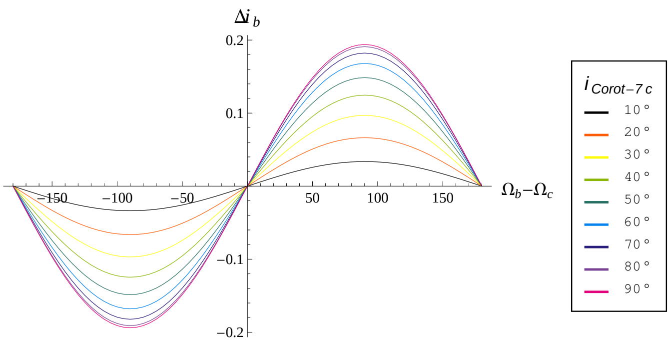

Fig. 6. Secular change in the inclination of CoRoT-7b per year as a function of the relative position of the ascending node and the inclination of CoRoT-7c

4.2. Analytical estimation

We analytically estimate the change of the orbital elements in the two planet case (subscripts i and j)using the differential equations for the secular perturbation of the orbital elements e, ω, i, Ω from Stumpf (1965):

$$\frac{\mathrm{d}e_i}{\mathrm{d}t} = \frac{d_i}{e_i}\left(f_i g_j - g_i f_j\right) = d_i e_j \sin\left(\omega_j - \omega_i\right) \tag{4.1a}$$

$$\cos i_i \frac{\mathrm{d}i_i}{\mathrm{d}t} = c_i \sin i_j \sin\left(\Omega_i - \Omega_j\right) \tag{4.1b}$$

$$\frac{\mathrm{d}\omega_i}{\mathrm{d}t} = c_i - d_i \frac{e_j}{e_i} \cos\left(\omega_j - \omega i\right) \tag{4.1c}$$

$$\frac{\mathrm{d}\Omega_i}{\mathrm{d}t} = -c_i \left\{1 - \frac{\sin i_j}{\sin i_i} \cos\left(\Omega_i - \Omega_j\right)\right\} \tag{4.1d}$$

In the case of a heavy central body (the star) and two planets, the right side of equations 4.1 can be assumed to be constant ignoring the mutual periodic perturbations. The orbital elements e, ω, i, Ω can then be described as slowly increasing or decreasing functions of time. The differential equation for the inclination 4.1b can thus be written as

$$\Delta i_i = -c_i \sin\left(\Omega_j - \Omega_i\right) \frac{\sin i_j}{\cos i_i} \tag{4.2}$$

depending only on the current values of i_i, i_j, Ω_i and Ω_j. The c_i are described by

$$c_i = \frac{1}{4} m_j n_i b_1^{(3/2)} \tag{4.3}$$

where $b_1^{(3/2)}$ is the Laplace coefficient of the first order. The $b_1^{(3/2)}$ depend on the ratio of the orbital distance of the two planets α and are calculated as follows:

$$b_k^{(s)} = \frac{2}{\pi} \int_0^{\pi} \frac{\cos k\gamma}{(1 - 2\alpha\cos\gamma + \alpha^2)^s} \mathrm{d}\gamma, \tag{4.4}$$

with $\alpha = \frac{a_i}{a_j}$.

Thus, for a given set of i_i, i_j, Ω_i and Ω_j it is possible to estimate the change Δi using 4.2. Figs. 6 and 7 show the secular change in inclination of CoRoT-7b in degrees per year as a function of the relative position of the ascending node $\Delta\Omega = \Omega_j - \Omega_i$ and the inclination of the other planet. If we take into account only the perturbation of planet CoRoT-7c on CoRoT-7b, the change in its inclination occurs at a rate of $\pm 0.2°$ per year at a separation of the ascending nodes of $\pm 90°$. Considering only the perturbation of CoRoT-7d, the change is much smaller, namely $\pm 0.06°$ per year (see Figs. 6 and 7). The initial value for the inclination of CoRoT-7b was assumed to be 1° in both calculations.

The results from this analytical approach fit the data from numerical integration very well, as can be seen in the following graphs: Figs. 8 (analytical model) and 9 (numerical model) show the change in Δi_{7b} after 3 years as a function of Ω_{7c} and Ω_{7d}, again with an initial inclination $i_{7b} = 1°$.

4.3. Extension to the three planet case

Since the data analysis of Hatzes et al. (2010) lead to the conclusion that (at least) three planets exist in the extrasolar planetary system CoRoT-7, we investigated the combined influence of different initial conditions for CoRoT-7c and CoRoT-7d on the inclination of the transiting planet. Here we ignored the possible differences in the ascending nodes of the three planets and set all to the same value. This assumption may be somewhat artificial but the parameter space is so large that this is the only way to estimate possible changes of the i_{7c}. We varied the inclinations of both outer planets from normal prograde to retrograde orbits ($0° < i < 180°$).

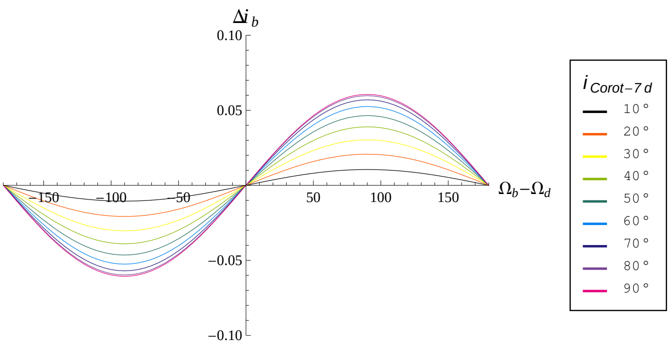

Fig. 7. Secular change in the inclination of CoRoT-7b per year as a function of the relative position of the ascending node and the inclination of CoRoT-7d (note the difference in scale to Fig. 6)

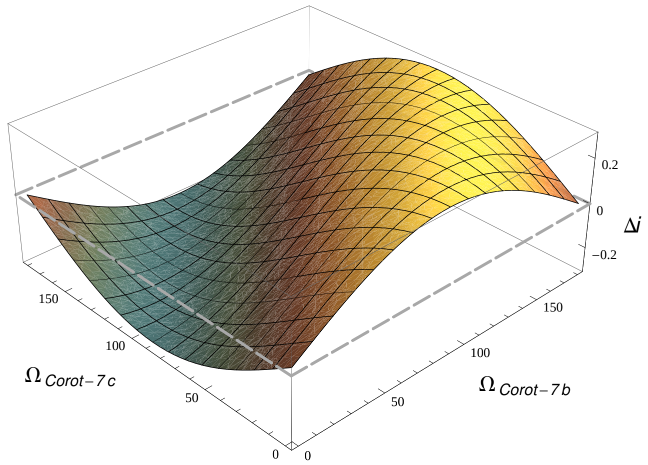

Fig. 8. Change in the inclination of CoRoT-7b after 3 years as a function of the relative position of the ascending node of CoRoT-7b and CoRoT-7c using equation 4.2.

– After 1 year: The results of the integration for such a short time interval (Fig. 10) show that only for large inclinations of CoRoT-7c ($i \sim 60°$) CoRoT-7b would suffer from changes in the order of 1° without a big influence of the inclination of CoRoT-7d. On the other hand the outermost planet would have a significant influence only if its orbital plane was almost perpendicular to the plane of CoRoT-7b. This is also clear from the results of analytical computations (see Figs. 6 and 7).
– After 3 years: During the lifetime of the CoRoT satellite the change in the inclination of CoRoT-7b would be observable within the given error bars, when both outer planets would have inclinations in the order of several tenths of degrees (Fig. 11).
– After 10 years: It is evident from Fig. 12 that for such a long time interval of observations the changes could be significant even for only slightly inclined orbits of one or both of the outer planets.

The cross-shaped white area (for retrograde orbits) of the parameter space would lead to unstable orbits even in short time scales.

5. Transit duration

Several formulas have been published to calculate the duration of transits (e.g. Kipping 2008; Seager & Mallén-Ornelas 2003). To determine the transit duration of CoRoT-7b for different apparent inclinations we applied the following formula of Seager & Mallén-Ornelas (2003)

$$t_T = \frac{P}{\pi} \arcsin\left(\frac{R_*}{a} \left[\frac{\left(1 + \frac{R_P}{R_*}\right)^2 - \left(\frac{a}{R_*} \cos i\right)^2)}{1 - \cos^2 i} \right]^{1/2} \right), \tag{5.1}$$

being valid only for circular orbits. Note that in our calculations we always consider the total transit duration, i.e. including ingress and egress of the planetary disk.

The numerical integrations of the CoRoT-7 system for ten years (see Fig. 12) resulted in a change in the inclination of CoRoT-7b of up to 3° . Table 2 shows the corresponding change in the transit duration.

The total duration of the transit, as calculated with Formula 5.1 – which in this case exactly describes the transit geometry – is 66.4 minutes. This is in very good agreement with the transit duration published by Léger et al. (2009) of 1.125 ± 0.05h = 67.5 ± 3 min. If the apparent inclination of CoRoT-7b decreases by a value of 3° , the transit duration decreases by approx. 32 minutes,

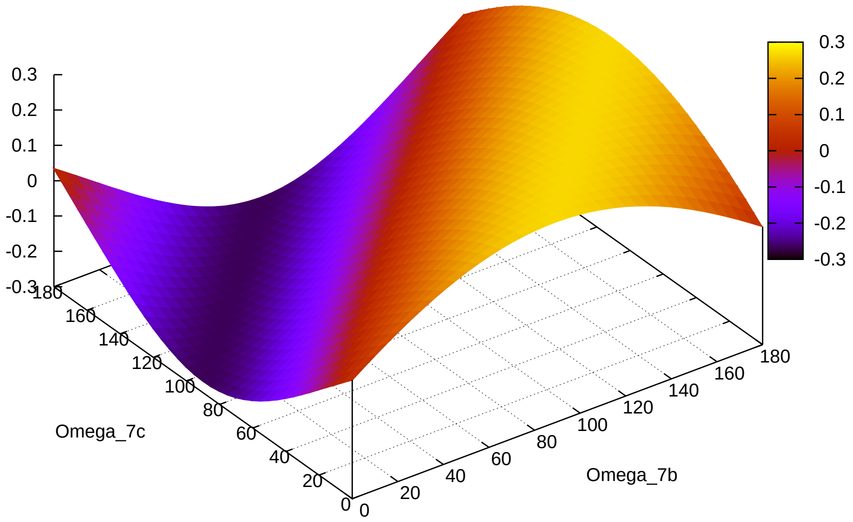

Fig. 9. Change in the inclination of CoRoT-7b after 3 years as a function of the relative position of the ascending node of CoRoT-7b and CoRoT-7c using results from numerical integrations

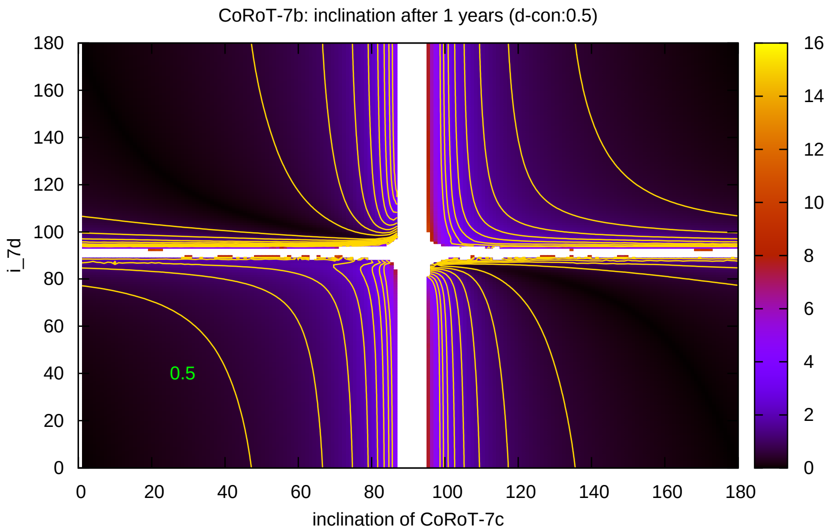

Fig. 10. Change in the inclination of CoRoT-7b per year as a function of the relative position of the ascending node of CoRoT-7b and CoRoT-7c using results from numerical integrations.

whereas if the inclination increases by 3° the transit duration is approx. 16 minutes longer (see Table 2). This could be easily observed by the CoRoT satellite. Our numerical calculations suggest – depending on the exact conditions – that a 1° change in the inclination of CoRoT-7b could be expected after three years, and a 3° change should be possible over the course of 10 years (see Section 4.3). One a side note, if the apparent inclination of CoRoT-7b is less than 76.2° the transit cannot be observed any more.

Since CoRoT-7 is a multiplanetary system with at least two planets – as already pointed out (Queloz et al. 2009; Hatzes et al. 2010; see Table 1) – we also investigated the possibility of CoRoT-7c or CoRoT-7d becoming a transiting planet. Taking the orbital plane of CoRoT-7b to be the reference plane of the system, we calculated the transit possibility as a function of inclination and longitude of the ascending node in reference to CoRoT-7b. These calculations could not be done using formula 5.1, which takes into account only the apparent inclination, but not the longitude of the ascending node. This is an important orbital parameter for determining the transit probability. We adopted a semi-analytical approach using the computer algebra software *Wolfram*

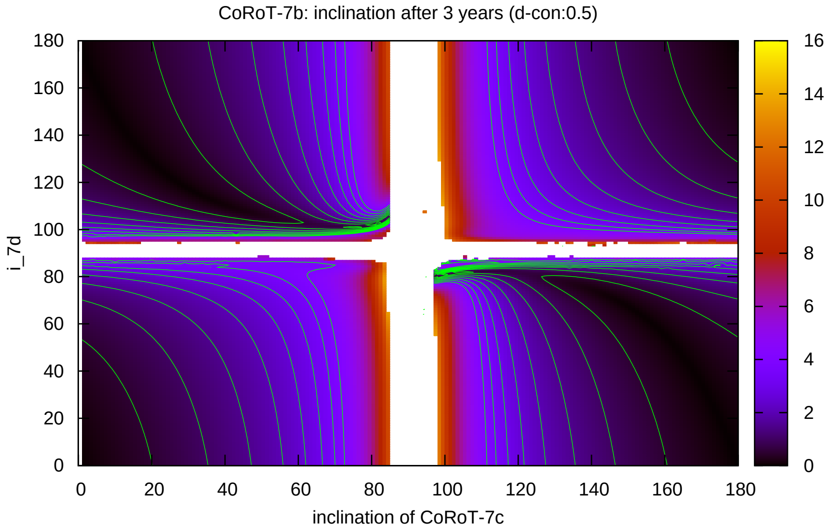

Fig. 11. Change in the inclination of CoRoT-7b per year as a function of the relative position of the ascending node of CoRoT-7b and CoRoT-7c using results from numerical integrations.

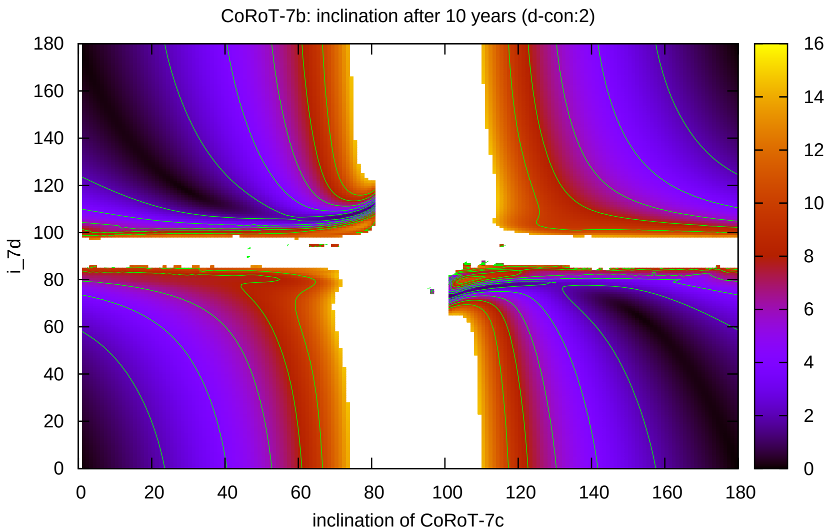

Fig. 12. Change in the inclination of CoRoT-7b per year as a function of the relative position of the ascending node of CoRoT-7b and CoRoT-7c using results from numerical integrations.

Mathematica^{TM}. The planetary orbit is represented by a 3D parametric equation. The full representation of the orbit is obtained by combining a parametrization of the position of the orbital plane according to the Keplerian elements e, a, i, ω and Ω, with a rotation of the system according to the point of view of the observer. This approach allows a consistent choice of the reference plane for multiplanetary systems, and accounts for the apparent inclination the system is observed under. We use an extended projection of the stellar disk in direction of the observer, represented by a cylindrical parametrization with a diameter of $R = R_* + R_P$, so that we get the total transit duration. The intersection of the orbit with the projection of the disk yields two positions t_1 and t_2 on the orbital curve, which correspond to the starting and ending points of the transit. For a circular orbit, which we assume for the planets of the CoRoT-7 system, the parameter t of the orbital curve is equivalent to the mean motion of the planet. In order to obtain the amount of time passing between the planet entering and exiting the stellar disk we calculate the length l of the arc of the orbital curve between the two points t_1 and t_2

i [degree]	77.1	77.6	78.1	78.6	79.1	79.6	80.1 [1]	80.6	81.1	81.6	82.1	82.6	83.1
Δt_{trans} *[min]*	34.5	42.3	48.6	53.9	58.6	62.7	66.4	69.7	72.7	75.4	77.8	80.1	82.1

[1] currently adopted value of inclination (http://exoplanet.eu)

Table 2. Change in the transit duration of CoRoT-7b.

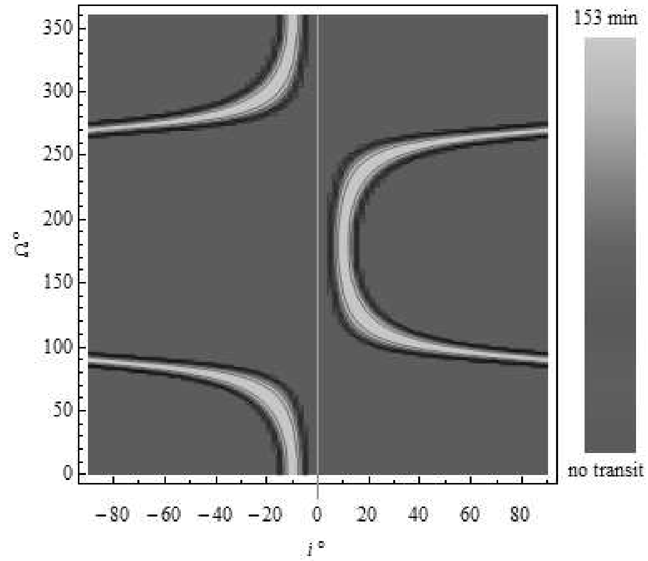

Fig. 13. Duration of a possible transit of CoRoT-7c as a function of inclination and longitude of the node. The transit duration is given in minutes and indicated by color coding and contour lines.

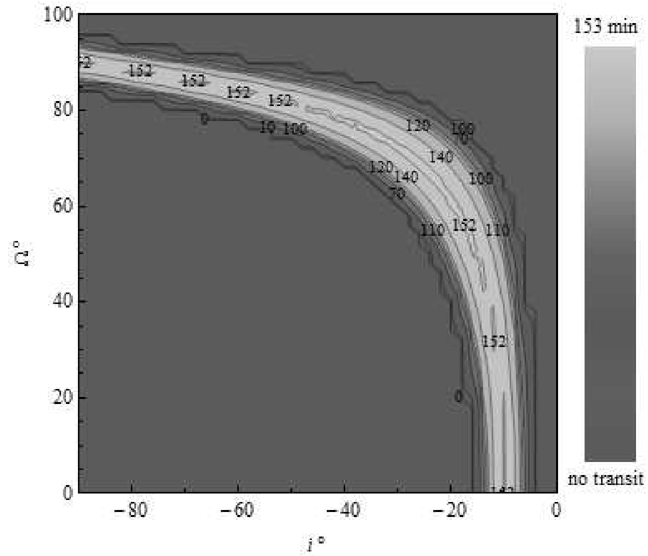

Fig. 14. Detail of Fig. 13 with labeled contour lines.

$$l = 2\pi a \frac{t_2 - t_1}{360°} \tag{5.2}$$

The ratio of the orbital length during the transit to the circumference of the orbit L corresponds to the ratio of the duration of the transit to the planetary period P. The transit duration can then be written as

$$t_{Transit} = \frac{l}{L} P. \tag{5.3}$$

For investigating the possibility of CoRoT-7c or CoRoT-7d becoming a transiting planet, we had to adopt a value for the planetary radii which are currently not known. CoRoT-7c has a minimum mass of 8.4 M_{Earth}, positioning it right between Earth and

Neptune. So we assumed the density of CoRoT-7c to be the mean value of the densities of Earth and Neptune, yielding a radius of 0.22 $R_{Jupiter}$. CoRoT-7d has a minimum mass very similar to the mass of Neptune (16.5M_{Earth}), so it was assumed to have the same density, corresponding to a radius of 0.34 $R_{Jupiter}$. Figures 13 and 14 show the duration of a transit of CoRoT-7c as a function of its inclination and the position of the ascending node. The reference plane is fixed to the plane of CoRoT-7b and the ascending node of CoRoT-7b is assumed to be in the direction of the observer. Thus, the value of the inclination as shown in Fig. 13 is not the apparent inclination as it would appear to an observer, but the in-system inclination with respect to the plane of CoRoT-7b. Fig. 14 is showing a enlarged detail of Fig. 13 with labeled contours of equal transit duration. The same calculation was done for CoRoT-7d, and qualitatively the same behaviour was found. Due to the similarity of the plots – the only difference being in the scale – we refrain from showing this figure. The maximum transit duration is 153 minutes for CoRoT-7c, as can be seen in Figs. 13 and 14, and 217 minutes for CoRoT-7d.

6. Conclusions

In this investigation we estimated the TDV caused by inclined additional planets which reaches – although relatively small – values of some degrees and is therefore detectable with the CoRoT satellite. This possibility stems from the fact that the CoRoT-7 system is a rapidly evolving extrasolar system with very close-in planets.

We did our study using numerical integrations for the long term development of the system, as well as an analytical approach for short time intervals in the order of years. It turned out the system is quite stable even in the 3 planet model. A quantitatively new result is the dependence on the difference in the ascending node on the short time development of CoRoT-7b. The small phase shift in the dynamical development is not important for the qualitative behaviour for long time, but essential for the short time evolution of the orbit of CoRoT-7b.

In our determination of the duration of the transit caused by the change of the inclination of CoRoT-7b we also discussed what kind of orbits of the outer planet(s) would lead to a transit of these planets.

Despite the constraints given by the incompleteness of the data derived from observations the main conclusion of our study is that after three years of observation of the EPS CoRoT-7 we would be able to determine – via transit observations from space of the CoRoT satellite and additional ground based RV – whether the two (three planets) are on mutually inclined orbits or whether they have just small inclinations of the order of $i < 10°$. More work has to be done for a more detailed analysis with numerical studies but also with analytical approaches (e.g. Borkovits et al. 2003, 2007) comparable to those which have been undertaken for the investigation of the change in occultations of eclipsing binaries caused by an additional star.

Acknowledgements. V. Eybl wants to acknowledge the support from the Austrian FWF project 18930-N16.

References

Batygin, K., Laughlin, G., Meschiari, S., et al. 2009, ApJ, 699, 23
Borkovits, T., Csizmadia, S., & Forgács-Dajka, E. 2010, in preparation
Borkovits, T., Érdi, B., Forgács-Dajka, E., & Kovács, T. 2003, A&A, 398, 1091
Borkovits, T., Forgács-Dajka, E., & Regály, Z. 2007, A&A, 473, 191
Gilliland, R. L., Brown, T. M., Christensen-Dalsgaard, J., et al. 2010, PASP, 122, 131
Hatzes, A., Dvorak, R., Wuchterl, G., et al. 2010, in preparation
Kipping, D. M. 2008, MNRAS, 389, 1383
Léger, A., Rouan, D., Schneider, J., et al. 2009, A&A, 506, 287
Libert, A. & Tsiganis, K. 2009a, A&A, 493, 677
Libert, A. & Tsiganis, K. 2009b, MNRAS, 400, 1373
Lovis, C. et al. 2010, submitted to A&A
Mardling, R. A. 2010, ArXiv e-prints
Nagasawa, M., Ida, S., & Bessho, T. 2008, ApJ, 678, 498
O'Donovan, F. T., Charbonneau, D., Mandushev, G., et al. 2006, ApJ, 651, L61
Queloz, D., Bouchy, F., Moutou, C., et al. 2009, A&A, 506, 303
Scuderi, L. J., Dittmann, J. A., Males, J. R., Green, E. M., & Close, L. M. 2010, ApJ, 714, 462
Seager, S. & Mallén-Ornelas, G. 2003, ApJ, 585, 1038
Stumpf, K. 1965, Himmelsmechanik Band II. Das Dreikörperproblem (Deutscher Verlag der Wissenschaften)
Thommes, E. W. & Lissauer, J. J. 2003, ApJ, 597, 566